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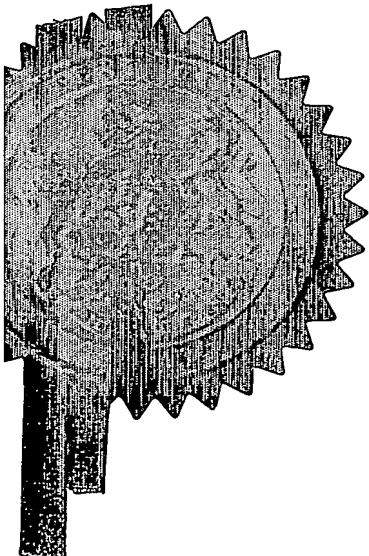
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AA 1602 GB

2. Patent application number

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09 AUG 2002

3. Full name, address and postcode of the or of each applicant (underline all surnames)

JOHNSON MATTHEY PUBLIC LIMITED COMPANY  
2-4 COCKSPUR STREET  
TRAFALGAR SQUARE  
LONDON SW1 5BQ

Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation GB

0536268004

4. Title of the invention

ENGINE EXHAUST TREATMENT

5. Name of your agent (if you have one)

ANDREW DOMINIC NUNN

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

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Patents ADP number (if you know it)

08083206001

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Country

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Date of filing  
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7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

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## ENGINE EXHAUST TREATMENT

The present invention relates to engine exhaust gas treatment, in particular to a system and process applicable to soot-containing gas.

5

Whereas filtering soot from engine exhaust gas by ceramic wall-flow filters has become well established, use of metal-based filters is less so. Metal-based filters were disclosed *inter alia* in US-A-4,207,936 and US-A-4,902,487 and in SAE papers 820184 (Enga et al.) and 890404 (Cooper, Thoss). They reached an advanced stage of development in Johnson  
10 Matthey's 'Catalytic Trap Oxidiser' ('CTO'), but appear not to have successfully competed with wall-flow filters in the commercial market. We have recently identified systems in which metal-based filters can be used with advantage.

15 ACCORDING TO THE INVENTION a lean-burn internal combustion engine currently or potentially producing a soot-containing exhaust gas is characterised by:

- a. an exhaust gas treatment system comprising a soot filter packed with flat strip metal;  
and
- b. means in-system to subject soot collected on the filter to oxidant more active than  
molecular oxygen; and/or
- 20 c. an exhaust gas treatment system comprising a soot filter packed with flat strip metal;  
and
- d. low sulfur fuelling and lubrication giving exhaust gas of less than 20ppm SO<sub>2</sub>.

25 The exhaust gas from such an engine typically contains the gaseous components soot (or particulate matter) HC, CO, NO<sub>x</sub>, CO<sub>2</sub>, H<sub>2</sub>O, O<sub>2</sub> and N<sub>2</sub>. The means to remove by combustion the soot collected on the filter preferably operates continuously. The oxidant more active than O<sub>2</sub> is for example ozone or plasma, most conveniently NO<sub>2</sub>. Such NO<sub>2</sub> is preferably provided, at least in part, by catalytic oxidation of the NO component of the NO<sub>x</sub> e g on a NO-oxidation catalyst upstream of the filter. Such catalyst may be supported on metal, conveniently of the  
30 type used in the filter, but at a lower packing density, to permit passage of soot particles. Alternatively or additionally the filter packing may carry a layer catalytic for soot oxidation, possibly by a mechanism involving oxidation of NO to NO<sub>2</sub>. If the engine-out NO<sub>x</sub> available in the gas is insufficient to combust the soot continuously, more may be introduced, e g by

introduction of plasma or NOx or nitric acid, possibly as ammonia oxidation gas produced on vehicle.

The external structure of the filter may have features providing operational advantages. For example, it may be formed as a monolith easily inserted into or withdrawn from a reactor shell. Whether monolithic or not, it may be disposed as a cartridge in an outer shell, easily insertable or withdrawable. It may be capable of electrical conduction as a whole, thus permitting electric heating at cold start. Such electrical conduction may be used in constructing a monolith, by effecting local welding between adjacent strips; if the filter is to be disposed in an outer shell. It may contain an axial metal rod to act during such welding as one electrode, the shell acting as the other. Further external features are mentioned below.

The metal of the filter should be capable of withstanding the exhaust treatment process conditions. Since the filter can be replaceable more easily than a ceramic filter, and its material can be recovered for re-use, the use-life of the filter need not be as long as for a ceramic filter. It is possible to envisage replacing the filter at the normal service interval of a vehicle.

Typically the metal is a corrosion resistant iron alloy. Typical alloys contain nickel and chromium and minor constituents as in Type 300 or Type 400 stainless steels. Which is used may depend on whether the exhaust gas treatment system is required to operate temporarily in rich conditions, in which some stainless steels are unstable. For a wide variety of exhaust compositions a preferred iron alloy contains at least 11.5% Cr, 4% Al and 0.02-0.25% minor constituents such as rare earth, zirconium or hafnium. The metal in a filter may be a mixture of different compositions, possibly including a component providing electrical conduction bridges or a welding function.

The filter may have, wholly or domain-wise, a regular structure, for example coiled, woven or knitted. The metal strip of the filter may be for example up to 2, especially in the range 0.1 to 0.5mm, wide. It should be thick enough to afford mechanical strength in the conditions in which it is to be used. Typically its thickness is in the range 0.2 to 0.8 of its width. Suitably its geometric surface area per unit length is in the range 1.2 to 1.5 times that of the same weight of metal in circular cross-section. It is suitably the product of flattening circular-section wire. The metal in a filter unit may be a mixture of strip dimensions and may include circular-section wire as unflattened interlengths or as added sub-units.

A catalytic coating on the filter typically comprises a washcoat of oxide such as alumina with possibly rare earth and an active material especially Pt or Pd or oxides of Cs and V. The coating may contain perovskite. If catalytic oxidation of NO is used, the catalyst typically comprises Pt and/or Pd on such a washcoat. If ozone is used, the generator thereof may be for example a corona discharge tube through which air passes between two electrodes kept at a large potential difference; or may comprise a high-energy lamp. If plasma is used, the plasma generator may operate for example by corona discharge, surface plasma discharge or dielectric barrier discharge or comprise a dielectric packed bed or electron beam reactor. It may be enhanced by electromagnetic radiation such as microwave radiation. The generator may treat air or the whole of the exhaust gas or part of such gas before or after treatment.

The size of the filter(s) relative to the engine and any arrangements to introduce additional oxidant more active than  $O_2$  may be the subject of design features. In the simplest case filter capacity is large enough to consume the soot continuously, that is, with any accumulation during slow running being quickly removed in periods of fast running. A less expensive filter capacity is sized to accommodate larger accumulations of soot, sufficient to increase pressure-drop significantly before the next period of fast running. Such filter(s) preferably includes a bypass, the pressure-drop through which is equal to the design maximum tolerated pressure-drop. The bypass avoids engine stalling or low power that would result from excessive pressure-drop, but permits some soot emission to atmosphere. To cope with such soot emission a second stage such as a filter or impingement collector and/or an oxidation catalyst may be provided downstream of the bypass. The bypass, without or with second stage filter and/or oxidation catalyst, may be part of the filter cartridge.

The direction of gas flow through the filter and/or (if used) oxidation catalyst can be or have a component linear or transverse to the general flow direction. Transverse flow may be for example symmetrical, especially inwards to an outflow header axial in a cylindrical filter, or to a plenum in an oval-section or rectangular filter. Alternatively one-way cross-flow may be provided.

In a further elaboration of the process and system a succession of filter elements presents to the gas a different soot-treating capacity, for example collecting smaller and smaller particles, and/or providing graded catalytic environments. Preferably gas flow in the filter element(s) at

the inlet of the succession is, or has a component, transverse to the general direction of flow. the process and system includes subjecting soot to oxidant more active than molecular oxygen, successive filter elements may alternate with oxidation catalyst and/or with means to provide plasma or ozone. In such succession downstream filter element(s) and (if used) oxidation catalyst(s) may be ceramic.

A particularly useful system comprises, in downstreamward order, a plurality of metal-based filters for successively trapping smaller and smaller particles and at least one wall-flow filter for trapping yet smaller particles. In this system the pores of the wall-flow filter can be smaller than in single-stage wall-flow trapping, because the preceding metal-based filters have removed the larger particles that may have blinded or blocked, i.e. reduced the gas flow through, them. Any or all of the filters may be catalysed.

Instead or in addition a distinct NO-oxidation catalyst may be disposed upstream of at least the first filter. Such catalysis on and/or between filters can have the effect of restoring the NO<sub>2</sub> content, which may have had been decreased by reaction with soot in the preceding filter. The filters and, if present, catalysts, may be assembled as a single unit within a cartridge.

The invention provides *per se* the exhaust system, the preferred filters described herein and a method of operating an engine comprising the system.

The exhaust treatment system may include other integers as used or proposed, for example a three-way catalyst (TWC), nitrogen oxide (NO<sub>x</sub>) trap + regeneration means, selective catalytic reduction (SCR) e.g. using hydrocarbon or ammonia as reductant, lean-NO<sub>x</sub> catalysis, a sulfur oxides (SO<sub>x</sub>) trap regenerable or disposable. The engine and system may include control gear and on-board diagnosis gear as usual or adapted to novel features of the invention.

The lean-burn engine may be for example for compression ignition such as diesel, or spark ignition such as lean burn gasoline e.g. gasoline direct injection (GDI<sup>TM</sup>). It may have exhaust gas recirculation (EGR). It may be for light or heavy duty. To provide for the low SO<sub>2</sub> content of the exhaust gas, the S content of the fuel used should be less than 500, especially less than 50ppm w/w as S.

The invention is illustrated by the accompanying drawing, which shows in schematic section a diesel engine with exhaust treatment.

Referring to the drawing, item 10 indicates a 4-cylinder diesel engine having air inlet 12 and fuel inlet 14 fed with hydrocarbon of 5 ppm sulfur content at an air/fuel weight ratio of 30 for steady operation but variable as routinely practised. The engine exhaust 16 is fed to a cylindrical treatment reactor indicated generally by 18 and having insulated internal walls 20. Fitting snugly within walls 20 is filter cartridge 22. At the inlet end of cartridge 22 and occupying its whole diameter is catalyst bed 24, packed with knitted 310 stainless steel flattened wire 0.33mm wide and 0.2mm thick to 6% solid by volume, carrying an alumina washcoat and Pt at 70-100, possibly up to 300, g/ft<sup>3</sup> of bed volume, giving low-temperature light-off. The next downstream zone of cartridge 22 is occupied by annular feed channel 28 surrounding first filter 30 packed with the same flattened wire as in bed 24 but at 12% solid by volume and carrying a washcoat and soot oxidation catalyst. Filter 30 provides axial-inward gas flow to outlet 32. Feed channel 28 terminates longitudinally in bypass 34, the function of which will be explained. The next downstream zone is second filter 36, providing longitudinal gas flow. Axial to filter 36 is metal rod 38, the function of which is to be explained. Filter 36 is packed with the same flattened wire as used in bed 24 but at 16% solids by volume and carrying a soot oxidation catalyst. Filter 30 and/or 36 may be rigidified, at the time of construction, by electric internal spot welding using respectively the axial outlet or axial rod 38 as one electrode and the outer boundary member as the other electrode. Surrounding filter 36 is bypass channel 40. Bypasses 34 and 40 are shown shaded to indicate the possible, but not inevitable, inclusion of flow-obstructing material to provide balancing of pressure-drop with that of the filter when partly soot-bearing. Instead of or in addition to the soot oxidation catalyst on filter 36, there may be a second oxidation catalyst, similar to 24, between the filters.

In the operation of the system, NO in the exhaust gas entering bed 24 is largely oxidised to NO<sub>2</sub>. Soot in the gas passes through bed 24 and is held on filter 30 where it is oxidised by the NO<sub>2</sub> to CO. If filter 30 is under-designed or an engine upset produces extra soot, soot accumulates in it and obstructs gas flow through it. At a design level of pressure-drop due to such obstruction, bypass 34 permits gas to pass through the exhaust system, so that engine operation can continue until soot-oxidising conditions return or remedial action is taken.

Likewise, if soot accumulates in filter 36 to a design level, bypass channel 40 permits gas to pass.

5 Filters as 30 and 36, and possibly others in succession, provide successively increasing geometric surface per unit volume, to trap finer particles or bypassed particles. Such successive filters need not include a bypass, if the entering concentration of soot is sufficiently less than in the first filtering stage. Such further stage(s) may include oxidation catalyst as mentioned above to restore the content of  $\text{NO}_2$  following reduction by soot on the preceding filter.

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**CLAIMS:**

1. A lean-burn internal combustion engine currently or potentially producing a soot-containing exhaust gas characterised by an exhaust gas treatment system comprising a soot  
5 filter packed with flat strip metal; and means in-system to subject soot collected on the filter to oxidant more active than molecular oxygen; and/or by an exhaust gas treatment system comprising a soot filter packed with flat strip metal; and low sulfur fuelling and lubrication giving exhaust gas of less than 20ppm SO<sub>2</sub>.
  - 10 2. An engine according to claim 1, wherein the oxidant more active than O<sub>2</sub> is ozone, plasma or NO<sub>2</sub>.
  3. An engine according to claim 2, wherein the NO<sub>2</sub> is provided, at least in part, by catalytic oxidation of the NO component of the NO<sub>x</sub> contained in the exhaust gas.
  - 15 4. An engine according to claim 3, wherein the system includes an NO-oxidation catalyst upstream of the filter, the catalyst being supported on metal of the type used in the filter, but at a lower packing density, to permit passage of soot particles.
  - 20 5. An engine according to any preceding claim, wherein the filter packing carries a layer catalytic for soot oxidation.
  6. An engine according to any preceding claim, wherein the filter has, wholly or domain-wise, a regular structure, for example coiled, woven or knitted.
  - 25 7. An engine according to any preceding claim, wherein the filter has at least one of the features: formation as a monolith easily inserted into or withdrawn from a reactor shell; whether monolithic or not, disposed as a cartridge in an outer shell, easily insertable or withdrawable therefrom; capable of electrical conduction as a whole, thus permitting  
30 electric heating at cold start; local electric welding between adjacent strips; an axial metal rod to act during such welding as one electrode, the shell acting as the other electrode.
  8. An engine according to any preceding claim, wherein the constructional metal of the filter  
is Type-300 or Type-400 stainless steel.
-

9. An engine according to any preceding claim, wherein the iron alloy contains at least 11.5% Cr, 4% Al and 0.02-0.25% minor constituents such as rare earth, zirconium or hafnium
- 5 10. An engine according to any preceding claim, wherein the width of the metal strip of the filter is up to 2, especially in the range of 0.1 to 0.5 mm and its thickness is 0.2 to 0.8 of its width.
- 10 11. An engine according to any preceding claim, wherein the filter comprises a catalytic coating comprising a washcoat including Pt or oxides of Cs and V.
- 15 12. An engine according to any preceding claim, comprising an exhaust gas treatment system comprising, in downstreamward order, a plurality of metal-based filters successively trapping smaller and smaller particles and at least one wall-flow filter trapping yet smaller particles.
- 20 13. An engine according to claim 12, wherein the filters are catalysed and/or a distinct NO-oxidation catalyst is disposed upstream of at least the first filter, whereby to restore the NO<sub>2</sub> content, which had been decreased by reaction with soot in the preceding filter.
- 25 14. An engine according to any preceding claim, wherein the filter capacity is large enough to consume the soot continuously, that is, with any accumulation during slow running being quickly removed in periods of fast running.
- 30 15. An engine according to any of claims 1 to 13, wherein the filter capacity is sized for accumulations of soot sufficient to increase pressure-drop significantly before the next period of fast running and the system includes a bypass the pressure-drop through which is equal to the design maximum tolerated pressure-drop through the filter(s) whereby to avoid engine stalling.
16. An engine according to claim 15, comprising means to limit soot emission to atmosphere, which means comprising a second stage such as a filter or impingement collector and/or an oxidation catalyst downstream of the bypass.
-

17. For use in an engine according to any preceding claim, an exhaust system or soot filter as defined in any one of those claims.
18. An exhaust system for a lean-burn internal combustion engine, which exhaust system comprising a filter for particulate matter and means for generating an oxidant for combusting particulate matter disposed on the filter, wherein the filter comprises flat strip metal.
19. A method of treating an exhaust gas of an internal combustion engine, which method comprising the steps of trapping particulate matter in the exhaust gas on a filter, generating an oxidant from remaining exhaust gas components and combusting the trapped particulate matter in the oxidant, wherein the filter comprises a flat strip metal.
20. Use of a soot filter comprising flat strip metal for treating an exhaust gas of a lean-burn internal combustion engine.
21. A lean-burn internal combustion engine substantially as described herein with reference to the accompanying drawing.
22. An exhaust system for a lean-burn internal combustion engine substantially as described herein.
23. A method of treating an exhaust gas of an internal combustion engine substantially as described herein.
24. The use of an exhaust system or a soot filter for treating exhaust gas of a lean-burn internal combustion engine substantially as described herein.
-

**ABSTRACT****ENGINE EXHAUST TREATMENT**

5           An exhaust system for a lean-burn internal combustion engine comprises a filter for particulate matter and means for generating an oxidant for combusting particulate matter disposed on the filter, wherein the filter comprises flat strip metal. The invention also comprises a method of treating an exhaust gas of an internal combustion engine, which method comprising the steps of trapping particulate matter in the exhaust gas on a filter, generating an  
10 oxidant from remaining exhaust gas components and combusting the trapped particulate matter in the oxidant, wherein the filter comprises a flat strip metal.

[Fig 1.]

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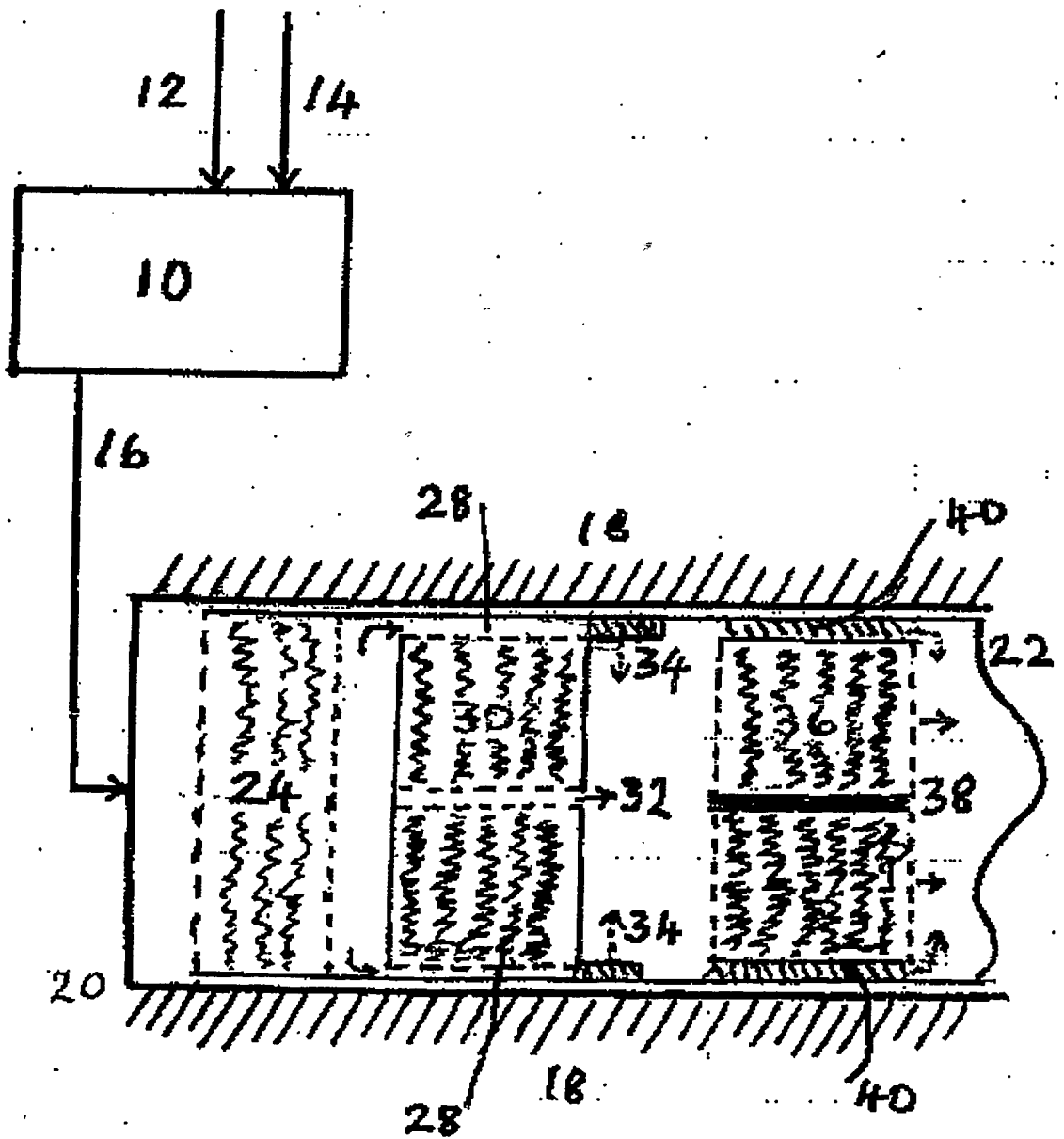


FIG. 1

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